Climate Change Trends and Vulnerabilities, Manzanar National Historic Site, California

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Climate Trends for the Area within Park Boundaries

- **Historical temperature** Average annual temperature in the park increased at the statistically significant rate of 2.1 ± 0.7ºC per century (3.1 ± 1.3ºF.) in the period 1950-2010 (Table 1, Figure 1).
- **Historical precipitation** Total annual precipitation decreased slightly in the period 1950-2010, but the rate was not statistically significant (Table 1, Figure 2).
- **Spatial patterns** Historical temperature increases were greater in the Owens Valley than in the Sierra Nevada and the White Mountains (Figure 3). In contrast, historical precipitation increases were lower in the Owens Valley (Figure 4).
- **California drought** A severe drought struck most of California, including the park, from 2012 to 2014, with the lowest 12-month precipitation total combining with the hottest annual average temperature (Diffenbaugh et al. 2015). The year 2014 was one of the ten driest from 1901 to 2014 (Williams et al. 2015). While the probability of low precipitation years has not increased, the hotter temperatures caused by human climate change have increased the probabilities of drought through increased probabilities of high temperature and low precipitation co-occurring in a single year (Diffenbaugh et al. 2015). For the State of California as a whole, human climate change accounted for one-tenth to one-fifth of the 2012-2014 drought (Williams et al. 2015). Under the highest emissions scenario, additional warming may increase the probability that, by 2030, any annual dry period co-occurs with drought-level heat (Diffenbaugh et al. 2015).
- **Projected temperature and precipitation** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project future heating at up to twice the recent historical rate and changes in precipitation (Table 1, Figure 5).
- **Projected precipitation** For projected average annual precipitation, climate models do not agree, with the average of all models projecting an increase, but one-third of the individual

models projecting decreases.

- **Aridity** Even if precipitation increases, temperature increases may overcome any cooling effects of increased precipitation, leading to increased evapotranspiration and overall aridity.
- **Extreme heat** Under the highest emissions scenario, models project an increase of 10 to 20 more days per year with a maximum temperature >35ºC (95ºF.) (Kunkel et al. 2013).
- **Extreme storms** Projections under the highest emissions scenario project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 5 to 10 years (Walsh et al. 2014).

Historical Impact in the Region Attributed to Human Climate Change

- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including counts in Death Valley, east of the park, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human climate change (La Sorte and Thompson 2007). Further analyses demonstrate poleward shifts in winter distributions of six raptor species listed by the NPS Inventory and Monitoring Program as breeding in the park (American Kestrel (*Falco sparverius*) and Red-tailed Hawk (*Buteo jamaicensis*)), or observed in the park (Golden Eagle (*Aquila chrysaetos*), Northern Harrier (*Circus cyaneus*), Prairie Falcon (*Falco mexicanus*), and (Rough-legged Hawk (*Buteo lagopus*)) (Paprocki et al. 2014).

Future Vulnerabilities in the Region

- **Groundwater** Analyses of Landsat data (1986-2006) and field transects (1991-2007) in two meadows ~25 km (~15 miles) south of the park found declines in shrub and herbaceous cover increased shrub dominance, and changes in dependence on groundwater based on management regime (Pritchett and Manning 2015). In the meadow with a regime of one-to several-year cycles of water table drawdown and recovery, cover decline and dominance-type conversion depended more on groundwater than precipitation. In the meadow with a regime of continuous water table drawdown, cover decline and dominance-type became precipitation-dependent. Non-cyclical management practices make groundwater-dependent ecosystems more vulnerable to water table decline (Pritchett and Manning 2015).
- **Alkali meadow** Research on herbaceous alkali meadow vegetation cover and precipitation from 1986 to 2002 in the Owens Valley demonstrates that meadow plant cover is more strongly correlated with groundwater depth than precipitation, except when groundwater drops

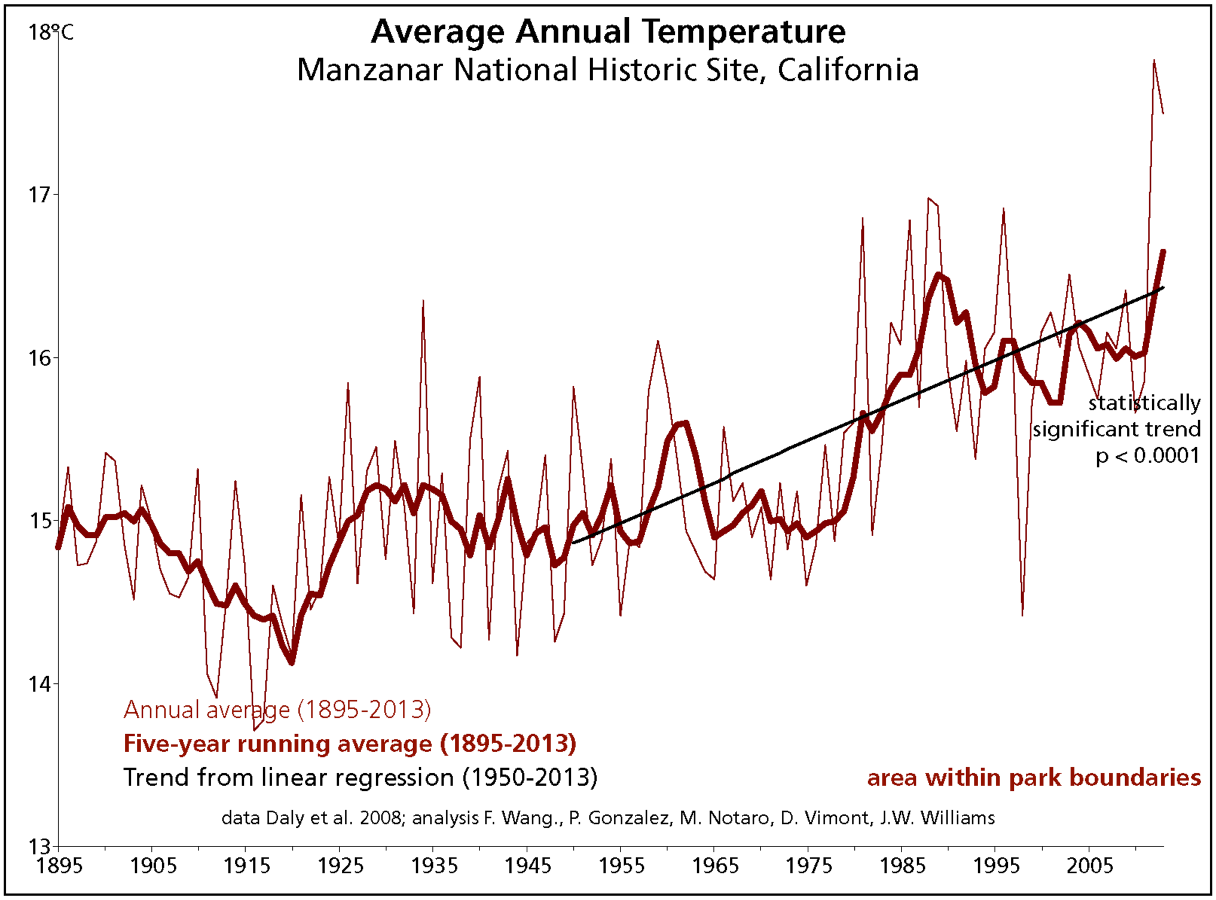
below 2.5 m, the effective rooting depth of perennial grasses and shrubs (Elmore et al. 2006). Only when groundwater was above 2.5 m did alkali meadows attain high plant cover. Perennial meadow vegetation becomes vulnerable to desiccation when groundwater declines below average maximum effective rooting depth (Elmore et al. 2006).

- **Plants (native)** Analyses of two plant species native to the park, box thorn (*Lycium andersonii*) and Mormon tea (*Ephedra nevadensis*) at the Free Air CO_2 Enrichment experiments at the Nevada Test Site (Hamerlynck et al. 2002, Pataki et al. 2000) found that box thorn grew relatively larger with more leaves under elevated CO_2 (Hamerlynck et al. 2002). Because Mormon tea had relatively fewer leaves under elevated CO_2, it would not benefit from increased carbon dioxide, which enhances growth in non-desert ecosystems (Pataki et al. 2000).
- **Plants (exotic)** Analyses of vegetation changes over 13 years across the Owens Valley showed that over-withdrawal of groundwater increased exotic annuals that do not rely on a constant supply of groundwater (nonphreatophytic) and reduced live cover of native plants that absorb water from a constant source on the ground (phreatophytic) (Elmore et al. 2003). The increase in exotic species could indicate a shift in the ecosystem from one buffered by stable groundwater to one that is sensitive to precipitation (Elmore et al. 2003).
- **Desert shrubs** Analyses in the Owens Valley of water-use efficiency of desert shrubs, including Great Basin sagebrush (*Artemisia tridentata*), found that desert shrubs are more tolerant to drought than grasses and wetland plants. Although standing crop increased, the lower root-to-shoot ratio found in desert shrubs suggests they would gain relatively little benefit from increased summer precipitation (Evans et al. 2013). Reduced groundwater will tend to reduce herbaceous cover more than shrubs (Evans et al. 2013).
- **Plague** Modeling of plague (caused by the bacterium *Yersinia pestis*), based on samples from three species present in the park (deer mice, (*Peromyscus maniculatus*), desert woodrats (*Neotoma lepida*), brush mice (*Peromyscus boylii*)), on species in and around the park (ground squirrels (*Spermophilus beecheyi*)), and coyote samples outside of the park indicates increased risk in some parts of California, but continued low probability (≤10%) of plague in the park under low emissions (scenario B2) or high emissions (scenario A2) by 2050 (Holt et al. 2009). While plague activity could be indirectly reduced at temperatures >35 ˚C due to resultant negative effects on flea fecundity, survival, and behavior, infected carnivores, especially coyotes, can also transmit plague at temperatures >35 ˚C (Holt et al. 2009).

Table 1. Historical rates of change and projected future changes per century in annual average temperature and annual total precipitation for the park as a whole (data Daly et al. 2008, IPCC 2013; analysis Wang et al. in preparation). The table gives the historical rate of change per century calculated from data for the period 1950-2013. The U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. The table gives central values with standard errors (historical) and standard deviations (projected).

	1950-2013	**2000-2100**
Historical		
temperature	+2.4 ± 0.4°C per century (4.3 ± 0.7°F.)	
precipitation	-8 ± 30% per century	
Projected (compared to 1971-2000)		
Reduced emissions (IPCC RCP2.6)		
temperature		+1.7 ± 0.8°C per century (+3.1 ± 1.4°F.)
precipitation		+7 ± 11% per century
Low emissions (IPCC RCP4.5)		
temperature		+2.8 ± 0.8°C per century (+5 ± 1.4°F.)
precipitation		+4 ± 10% per century
High emissions (IPCC RCP6.0)		
temperature		+3.2 ± 0.9°C per century (+5.8 ± 1.6°F.)
precipitation		+5 ± 12% per century
Highest emissions (IPCC RCP8.5)		
temperature		+4.8 ± 1°C per century (+8.6 ± 1.8°F.)
precipitation		+5 ± 13% per century

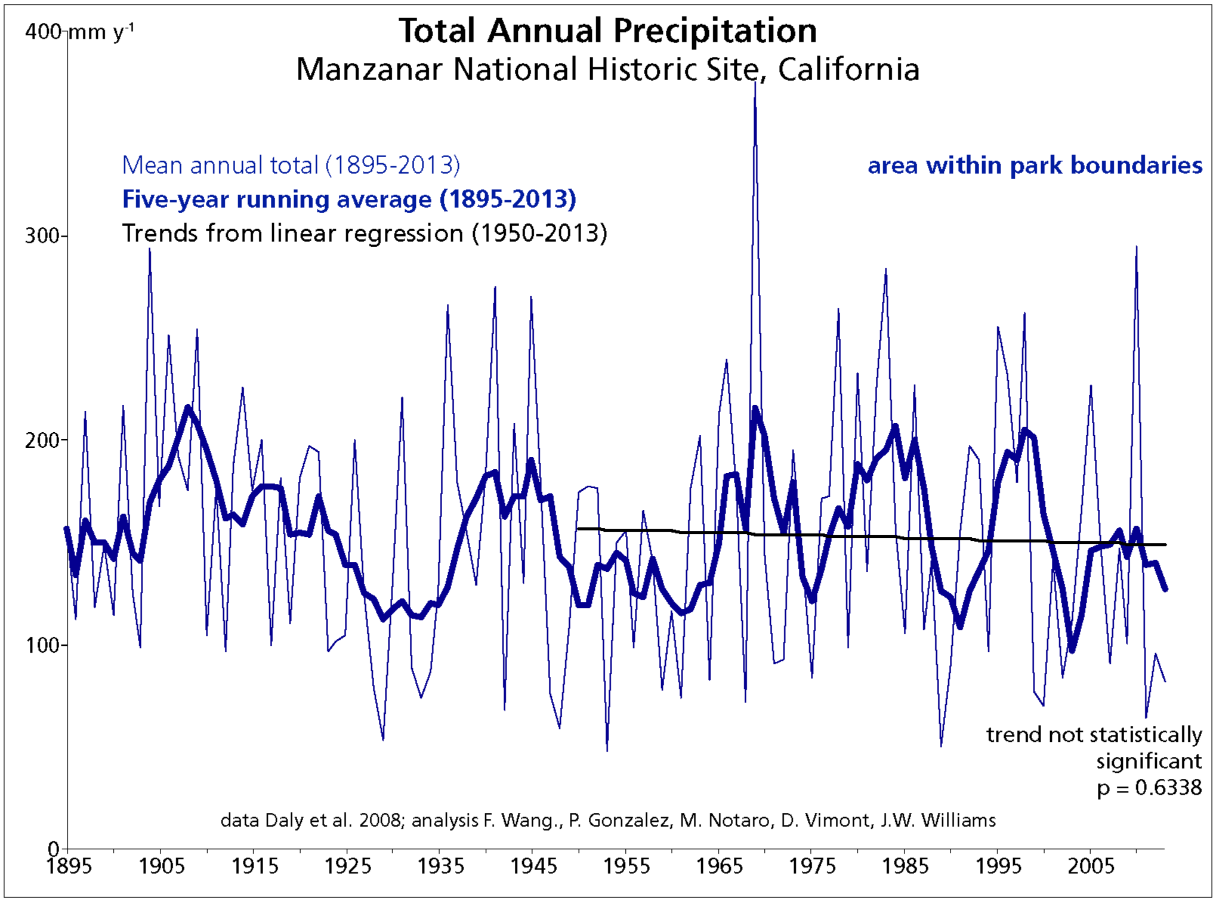
Figure 1.



Main conclusion: Temperature increased at a statistically significant rate in the park.

Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

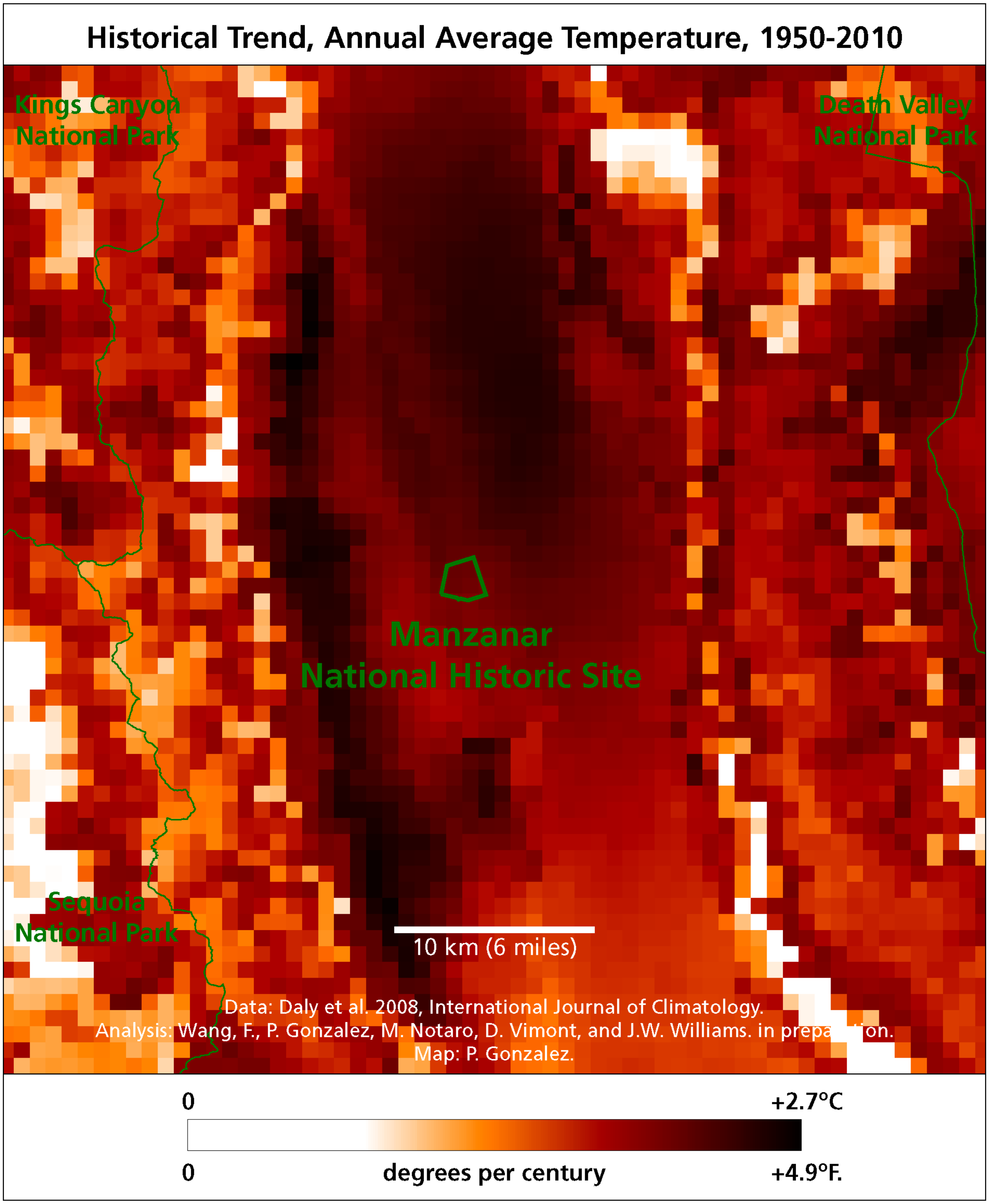
Figure 2.



Main conclusion: Precipitation did not show statistically significant trends in the park.

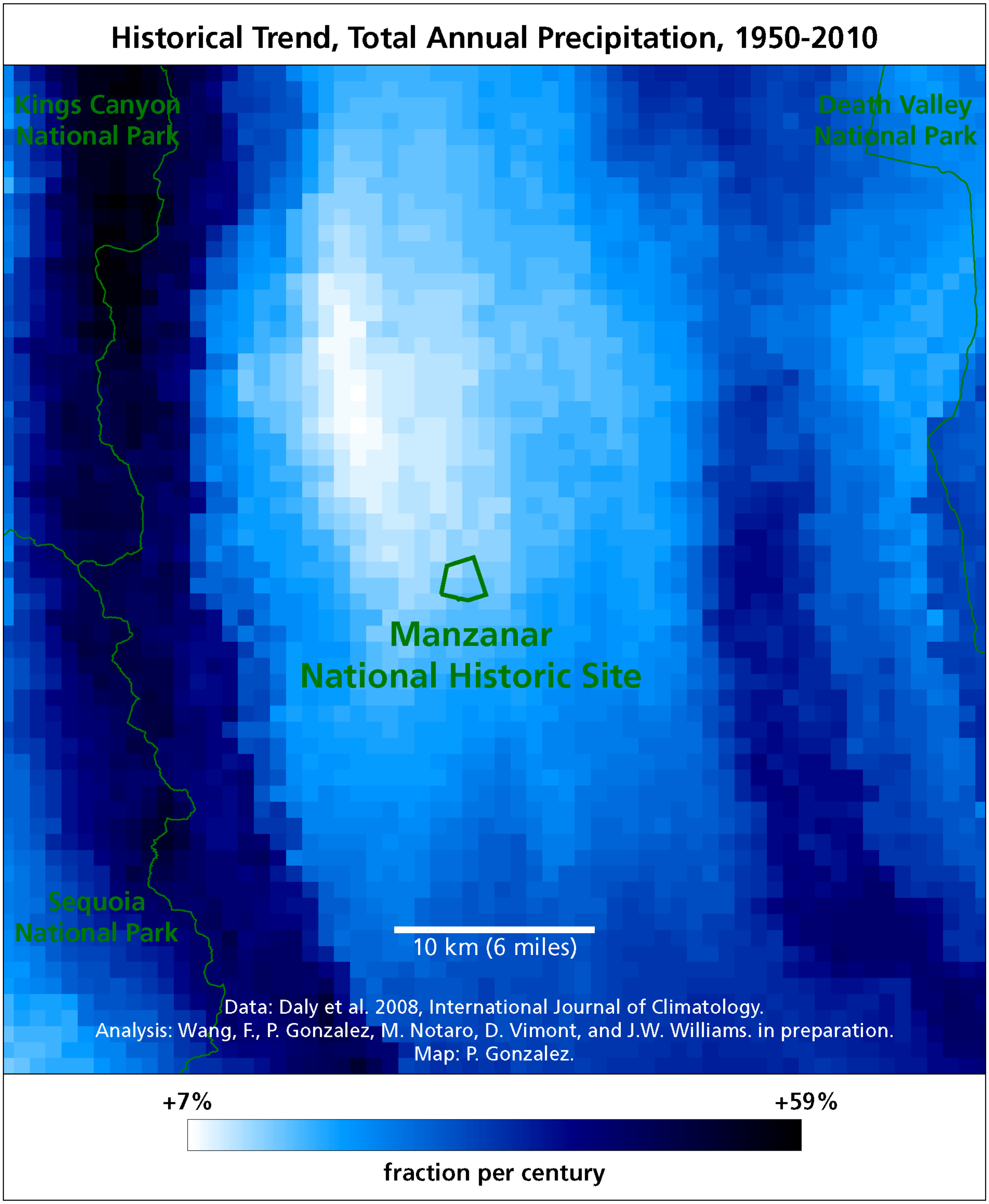
Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 3.



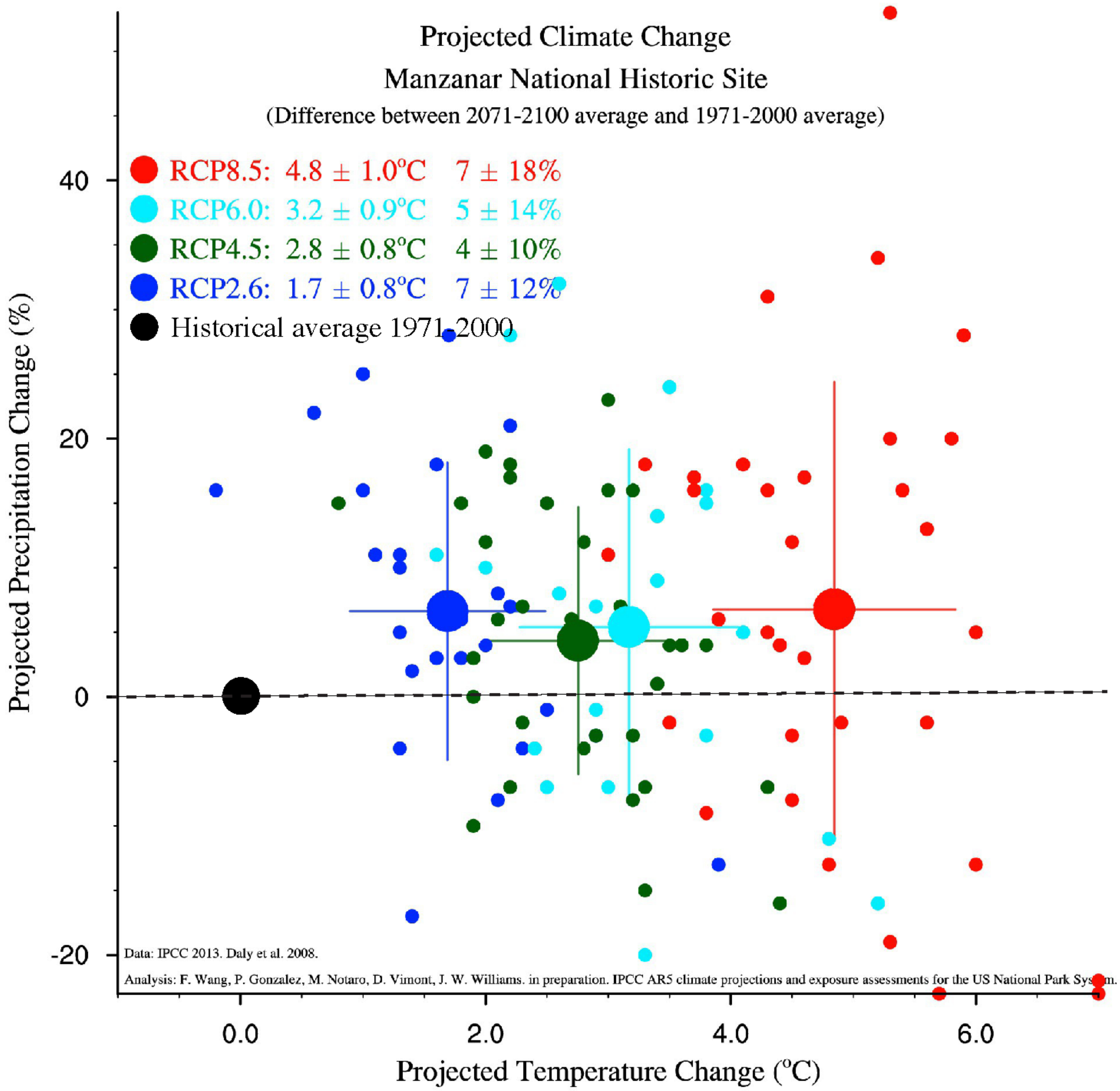
Main conclusion: Temperature increases are greater in the valley than in the mountains.

Figure 4.



Main conclusion: Precipitation increases are greater in the mountains than in the valley.

Figure 5.



Main conclusion: Models agree on projection of temperature increases in the park. Models do not agree on precipitation projections. Two-thirds of the models project precipitation increases.

Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios and the historical baseline. The lines are the standard deviations of each average value.

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